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(54) IMPROVEMENTS IN EPICYCLIC CHANGE-SPEED TRANSMISSION SYSTEMS

(71) We, A.B. VOLVO, a Swedish Body Corporate, of P.O. Box 382 S—405 08 Goteborg, Sweden, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to epicyclic change-speed power transmissions and concerns in particular epicyclic gearing comprising three epicyclic gear trains, the first and second trains each comprising an internally toothed annulus, an externally toothed sun wheel coaxial with the annulus and at least one planet wheel meshing with both the sun wheel and the annulus and rotatably mounted in a planet carrier which itself is mounted for rotation about the common axis of the sun wheel and the annulus, the gearing including braking means for selectively holding predetermined members of the gearing against rotation and clutching means for selectively establishing driving connections between predetermined members of the gearing to achieve a series of different driving ratios between input and output members of the gearing which are coaxial with the first and second gear trains.

According to the invention, there is provided epicyclic gearing comprising first, second and third epicyclic gear trains of which the first and second gear trains each comprise an internally toothed annulus, an externally toothed sun wheel coaxial with the annulus and at least one planet wheel meshing with both the sun wheel and the annulus and rotatably mounted in a planet carrier which itself is mounted for rotation about the common axis of the sun wheel and the annulus, the gearing including braking means for selectively holding predetermined members of the gearing against rotation and clutching means for selectively establishing driving connections between predetermined members of the gearing to achieve a series of different driving ratios between input and output members of the gearing which are coaxial with the gear trains, wherein an intermediate member is rotationally connected to the driving members of three independently operated friction clutches, the driven member of the first clutch is rotationally connected to the sun gear of the second train, the planet carrier of the second train and the annulus of the first train are rotationally connected to each other and the first selectively-operable braking means and to the driven member of the second clutch, the driven member of the third clutch is rotationally connected to the sun gear of the first gear train, the sun gear of the second train is rotationally connected to second selectively-operable braking means, and the planet carrier of the first train is rotationally connected to the annulus of the second train and to the output member and wherein the third epicyclic gear train is connected between the input of the gearing and the intermediate member and is constructed to yield selectively two alternative drive ratios in the same direction.

British Patent No. 1,331,048 demonstrates that a transmission containing three epicyclic gear trains will yield five forward drive ratios and one reverse ratio when controlled by three braking devices and three clutching devices, whereas it will be shown that a transmission constructed according to the invention will yield at least seven useful forward drive ratios and two reverse ratios when controlled by the three braking devices and four clutches and that the range between the lowest and the highest ratios is substantially greater than would be obtainable from the same three epicyclic gear trains employed in accordance with the said British Patent.

Another advantage of the said arrangement is to provide a series of forward drive ratios in which the increments between successive ratios at the higher end of the series, that is the end at which the output speed is greater in relation to input speed, may be smaller than those at the lower end of the series.

An advantageous modification consists in

introducing into a change-speed transmission of the type hereinbefore defined a free-wheel device adapted to form a unidirectional link between the sun wheel of the second train and a driving member which is common to the three clutches which provide the selective driving connections to the sun wheel of the first train, to the planet carrier of the second train and to the sun wheel of the second train, the said free-wheel device preventing the latter sun wheel from rotating faster than the said driving member when the latter member is rotating in the normal driving direction, but freely permitting relative rotation in the opposite sense.

This prevents a vehicle incorporating such a transmission from rolling backward on an up-hill gradient in the absence of sufficient driving torque at the input member of the transmission, so long as at least an indirect forward drive ratio is engaged.

Further, it facilitates and renders progressive a smooth transition from a direct-drive condition to an overdrive condition, and *vice versa*.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:—

Fig. 1 is the upper half of a diagram showing the layout of power transmission gearing for an automotive vehicle, and

Fig. 2 shows a modification which may be applied to the transmission shown in Fig. 1.

The transmission gearing shown in Fig. 1 comprises a rotatably mounted input member 21 which in use is connected to the output element of a torque-converter (not shown), the input element of which may be driven by a prime-mover such as a diesel engine. An intermediate member 1 carries a radial flange 2 to the periphery of which is attached a sleeve 3 carrying the driving elements of three independently-operable friction clutches C1, C2 and C3. The driven elements of the three clutches C1, C2 and C3 are carried by respective radial flanges 4, 5 and 6 mounted respectively on sleeves 7 and 8 and a central shaft 9 which are all coaxial with the intermediate member 1 and sun wheel S1.

At its other end, the central shaft 9 carries the sun gear wheel S1 of a first epicyclic gear train T1 which also includes a rotatably mounted internally toothed annulus A1 and a set of four planet pinions P1 each meshing with both the sun wheel S1 and the annulus A1 and each being rotatably mounted on a planet carrier L1 which itself is mounted for rotation about the common axis of the sun wheel S1 and the annulus A1.

The sleeve 8 terminates in a radial flange 11 forming part of the planet carrier L2 of a second epicyclic gear train T2 having a sun gear wheel S2 secured to and coaxial with the sleeve 7, an internally toothed annulus A2 coaxial with the second sun wheel S_2, and a set of four planet pinions P2 which are each rotatably mounted in the second planet carrier L2 and each mesh with both the second sun wheel S2 and the second annulus A2, the planet carrier L2 being mounted for rotation about the common axis of the sun wheel S2 and annulus A2.

The first annulus A1 is rotationally connected to the second planet carrier L2 by means of an extension sleeve 12 secured to the first annulus A1 and terminating in a flange 13 extending inwards to the second planet carrier L2.

The second annulus A2 is rotationally connected by means of an annular flange 14 to the first planet carrier L1 which in turn is secured to a radial flange 15 on a shaft 16 which is coaxial with the input member 1 and central shaft 9. The shaft 16 forms the output member of the transmission gearing.

A first brake B1 has its rotary element 17 rotationally connected to the first annulus A1 and can thereby when energised hold the first annulus A1 stationary. A second brake B2 similarly has its rotary element rotationally connected to the second sun wheel S2 and can accordingly be energised, independently of the first brake B1, to hold the second sun wheel S2 stationary.

A free-wheel device 20, for example of the roller or sprag type, may be installed between the first annulus A1 and the transmission casing to prevent the first annulus from rotating backward relative to the rotation of the input member 1 but allowing the annulus A1 to rotate freely in the forward direction when the first brake B1 is released. This facilitates smooth changing between ratios by avoiding the need for accurate co-ordination of the operation of the brake B1 with that of the other controlling elements.

The gear train T3 is similar to the trains T1 and T2 in that it comprises a sun wheel S3, an internally toothed annulus A3 and a set of four planet pinions P3 each meshing with both the third annulus A3 and the third sun wheel S3 and each being rotatably mounted on a planet carrier L3.

The input member 21 of the gearing is in use secured to the output member of a torque-converter (not shown). The input member 21 is rotationally connected to the third annulus A3 by a radial flange 22 secured to both the overall input shaft 21 and the third annulus A3. A further radial flange 23 rotationally connects the planet carrier L3 to the intermediate shaft 1 of the gearing. A third brake B3 has its rotary element 24 rotationally connected to the third sun wheel S3. The third train T3 may be locked up for *en bloc* rotation (with the brake B3 released) by means of a fourth clutch C4 which in this embodiment is connected between the third sun wheel S3 and the third planet carrier L3. A second free wheel device 25 is preferably included to pre-

vent backward rotation of the sun wheel S3, thereby avoiding the need for accurate synchronisation of operation of the brake B3 relative to that of the clutch C4.

It can be shown that the engaging of the various brakes and/or clutches selectively in different combinations of three at a time will yield potentially eight different forward drive ratios and two reverse ratios, between the overall input and output members.

The numerical values of these ratios will of course depend on the relative numbers of teeth on the sun wheel and annulus of each epicyclic train. Each of the three epicyclic trains can be designed to have a specific relationship in this respect in order to provide a series of at least seven useful forward drive ratios and two useful reverse ratios. For example, the number of teeth on the first sun wheel S1, relative to that on the first annulus A1, is preferably between 0.45 and 0.55 when the transmission is adapted for use in a high-speed highway vehicle and between 0.25 and 0.35 when it is adapted for use in an off-highway vehicle. The corresponding relationship between sun wheel S2 and annulus A2 in the second train is preferably between 0.25 and 0.35 and in the third train it is preferably between 0.5 and 0.6, the latter two trains being unaffected by the rôle for which the transmission is to be used.

A further feature of the layout shown in Fig. 1 is that ratios suitable for each of the two rôles of the transmission can be provided when specific tooth numbers assigned to the members of each train are compatible with the employment in each train of at least four equally-spaced planet wheels, while, at the same time, the number of teeth in the annulus is the same for each of the three trains, thereby facilitating production of the annulus members by enabling their teeth to be cut by a single set of broaching tools.

By way of example, a transmission suitable for a high-speed highway vehicle may have 80 teeth in each annulus while the sun wheels of the first, second and third trains have respectively 40, 24 and 44 teeth, the number of teeth on each planet wheel in each of these trains respectively being 20, 28 and 18. It can be shown that such a transmission will yield at least the following ratios of output speed to input speed when the brakes and/or clutches are selectively engaged in combinations as indicated in the brackets:

	Drive Ratio	Incremental ratio
1st speed (B1 + C3 + B3) =	0.215 : 1	
2nd — (B1 + C3 + C4) =	0.333 : 1	1.55
3rd — (B2 + C3 + B3) =	0.441 : 1	1.324
4th — (C1 + C3 + B3) =	0.645 : 1	1.462
5th* — (B2 + C2 + B3) =	0.839 : 1	1.3
6th — (C1 + C3 + C4) =	1.000 : 1	1.192
7th — (B2 + C2 + C4) =	1.3 : 1	1.3
Reverse 1 (B1 + C1 + B3) =	−0.194 : 1	
Reverse 2 (B1 + C1 + C4) =	−0.3 : 1	1.55

* A further speed corresponding to (B2 + C3 + C4) gives a drive ratio 0.684:1 which is too close to 4th speed to be useful.

The transmission constructed in accordance with the foregoing example can be adapted to suit an off-highway vehicle by exchanging the first sun wheel S1 for one having 24 teeth and exchanging the planet carrier L1 and planets P1 of the first train for a carrier having 28-tooth planets. The adapted transmission can be shown to yield at least the following ratios:—

		Drive Ratio	Incremental Ratio
1st speed	(B1 + C3 + B3) =	0.149 : 1	
2nd —	(B1 + C3 + C4) =	0.231 : 1	1.55
3rd —	(B2 + C3 + B3) =	0.365 : 1	1.58
4th —	(B2 + C3 + C4) =	0.565 : 1	1.55
5th* —	(B2 + C2 + B3) =	0.839 : 1	1.48
6th —	(C1 + C3 + C4) =	1.0 : 1	1.192
7th —	(B2 + C2 + C4) =	1.3 : 1	1.3
Reverse 1	(B1 + C1 + B3) =	−0.194 : 1	
Reverse 2	(B1 + C1 + C4) =	−0.3 : 1	1.55

* A further speed (C1 + C3 + B3) yielding a drive ratio of 0.645 is available.

In the modification shown in Fig. 2, a free-wheel device 31 is installed between the driving and driven members of the clutch C1 of the gearing of Fig. 1. The free-wheel device 31 is so constructed as to prevent the second sun wheel S2 from rotating faster than the driving sleeve 3 when the latter is rotating in the normal driving direction, but to permit free relative rotation in the opposite sense.

The free-wheel device 31 may be any of the known types in which there are first and second rotary members mounted coaxially with one another and a series of rollers or sprags disposed between the said members are adapted to wedge themselves to act as a driving link between the two members whenever there is a tendency to relative motion between the two members in one specific direction, while freely permitting relative motion of the two members in the opposite sense.

Such a free-wheel device may conveniently be installed within the clutch C1, the first rotary member of the free-wheel device being rotationally connected to the driving member of the said clutch and the second rotary member being rotationally connected to the driven member of the said clutch, which driven member is also rotationally connected to the sun wheel S2 of the second train T2.

The operation of the modification is as follows: When the transmission is set for any indirect forward drive ratio one or other of the clutches C2 and C3 must be engaged and one of the braking devices B1 or B2 is holding stationary either the first annulus A1 or the second sun wheel S2. In these circumstances any backward rotation of the common driving sleeve 3 is prevented by the free-wheel 31 because the sun wheel S2 of the second train would then either be locked by its brake B2 or would tend to rotate oppositely to the backward rotation of the common driving member 3, and since the latter is unable to have backward rotation it follows that the transmission output shaft 16 is also prevented from backward rotation in these circumstances; thus the vehicle is prevented from rolling backward irrespectively of the value of the driving torque from the prime-mover.

If the annulus A1 of the first train is provided with the free-wheel device 20 to prevent its backward rotation, it will be seen that the vehicle is thus also prevented from rolling back when the direct-drive ratio is engaged and none of the braking means is applied.

The vehicle may be driven forward in the direct-drive ratio by engaging the clutch C2 without engaging either of the clutches C1 or C3 since the free-wheel device 31 connected across C1 prevents the second sun wheel S2 from overrunning the common driving sleeve 3, so as its tendency under the influence of positive driving torque applied in these circumstances. From this driving condition it is possible to make the overdrive ratio effective merely by engaging the brake B2 to hold the second sun wheel S2, since the free-wheel device 31 will automatically release its grip when the brake B2 takes over the torque reaction from it. This renders unnecessary the usual critical operation of co-ordinating the release of a friction clutch with the effective engagement of the brake. Consequently, a smooth transition from the direct-drive ratio to overdrive ratio, and *vice versa*, can be achieved by progressively engaging (or disengaging, as the case may be) the overdrive-engaging braking means B2.

The brakes and clutches used in the construction of the invention may take any form,

but preferably they are of the type in which discs faced with suitable friction material are interleaved with other discs and pressed into mutual frictional contact by the application of fluid pressure to an actuator or actuators incorporated in the brake or clutch device. Details of their construction and of the construction of the gear trains may follow conventional practice in the art.

WHAT WE CLAIM IS:—

1. Epicyclic gearing comprising first, second and third epicyclic gear trains of which the first and second gear trains each comprise an internally toothed annulus, an externally toothed sun wheel coaxial with the annulus and at least one planet wheel meshing with both the sun wheel and the annulus and rotatably mounted in a planet carrier which itself is mounted for rotation about the common axis of the sun wheel and the annulus, the gearing including braking means for selectively holding predetermined members of the gearing against rotation and clutching means for selectively establishing driving connections between predetermined members of the gearing to achieve a series of different driving ratios between input and output members of the gearing which are coaxial with the gear trains, wherein an intermediate member is rotationally connected to the driving members of three independently operated friction clutches, the driven member of the first clutch is rotationally connected to the sun gear of the second train, the planet carrier of the second train and the annulus of the first train are rotationally connected to each other and to first selectively-operable braking means and to the driven member of the second clutch, the driven member of the third clutch is rotationally connected to the sun gear of the first gear train, the sun gear of the second train is rotationally connected to second selectively-operable braking means, and the planet carrier of the first train is rotationally connected to the annulus of the second train and to the output member and wherein the third epicyclic gear train is connected between the input of the gearing and the intermediate member and is constructed to yield selectively two alternative drive ratios in the same direction.

2. Epicyclic gearing according to claim 1, wherein the first, second and third clutches are all located physically on the same side of the second train as the input member, and the driven member of the second clutch is rotationally connected to the second planet carrier by a sleeve passing through the second sun wheel and its connection to the driven member of the first clutch, and the driven member of the third clutch is rotationally connected to the first sun wheel by a shaft passing through the sleeve.

3. Epicyclic gearing according to claim 1 or 2, wherein the third epicyclic gear train comprises a toothed third sun wheel, an internally toothed third annulus and at least one planet wheel rotatably mounted in a third planet carrier and meshing with both the third sun wheel and the third annulus, the third planet carrier being rotationally connected to the intermediate member, the third annulus being rotationally connected to the input member, and a fourth clutch is selectively-operably to connect two elements of the third train together to lock up the third train, and independently operable third braking means are operable to hold the third sun wheel stationary with the fourth clutch disengaged.

4. Epicyclic gearing according to claim 4, and including a free-wheel device for preventing backward rotation of the third sun wheel.

5. Epicyclic gearing according to any of the preceding claims, and including a free-wheel device adapted to form a unidirectional link between the second sun wheel and the intermediate member, the said free-wheel device preventing the second sun wheel from rotating faster than the intermediate member when the intermediate member is rotating in the normal driving direction, but freely permitting relative rotation in the opposite sense.

6. Epicyclic gearing according to claim 5, where the free-wheel device is incorporated in the first clutch.

7. Epicyclic gearing according to any of the preceding claims, characterised by a free-wheel device for preventing backward rotation of the first annulus.

8. Epicyclic gearing substantially as hereinbefore described with reference to Fig. 1 of the accompanying drawings.

9. Epicyclic gearing according to claim 8, modified substantially as hereinbefore described with reference to Fig. 2 of the accompanying drawings.

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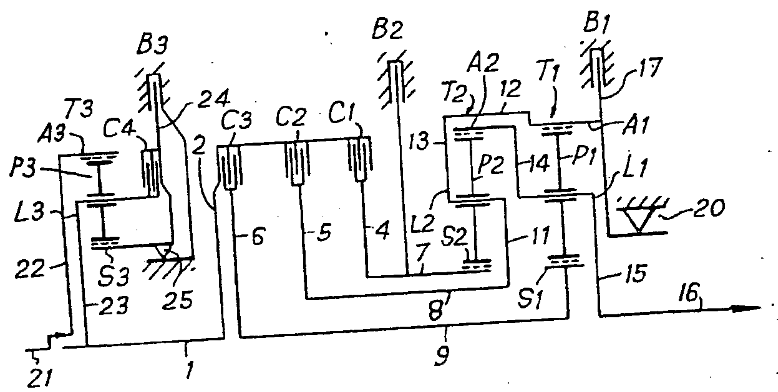
FIG. 1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T3
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B1
17
A1
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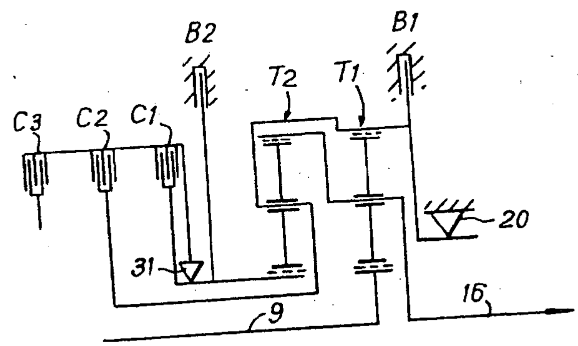
21

FIG. 2


B2
B1
C3
C2
C1
T2
T1
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16